Method and device for the registration of images

The invention relates to a method for the registration of a series of at least three temporally successively acquired images of an object, and also to a corresponding registration device. The invention also relates to a device for the temporally successive acquisition of a series of medical image data from an examination zone of an object to be examined, as well as to a computer program for carrying out such a method and/or for controlling such a device.

For the evaluation of temporally successively acquired images it is often necessary to register such images during a first step of the image processing operation in order to compensate notably for undesirable motions that have occurred during the acquisition of the images and that would falsify the evaluation result. Such motions may be motions of the object itself as well as motions of the image acquisition device. Registration in this context is to be understood to mean that it is determined how the various images have to be mapped on one another; notably the translations and/or rotations are determined whereto the object or the image acquisition device has been subject between the acquisition of the individual images that must be compensated prior to the evaluation of the images.

For example, when temporally successively acquired images of the night sky have to be combined or compared so as to derive astronomic data, it is first necessary to eliminate any motions of the image acquisition device, for example of the stand of the camera, and to determine the exact positional relationship between the images. The evaluation result would otherwise be falsified.

A further example in this respect is formed by medical image data, for example data from functional magnetic resonance tomography where often approximately 100 three-dimensional images are acquired. Motions of the head of the patient during the image data acquisition would definitely degrade the evaluation result, that is, the resultant functional survey image. Compensation for such motions, therefore, is an absolute must. A high registration accuracy is also necessary since even slight inaccuracies and interpolation errors would already give rise to artifacts in the resultant functional survey images.

According to known registration methods, for example as described in " Medical Image Matching - a review with classification", IEEE Eng. Med. Bio. 12, (1993) pp.

26-29, the registration is performed on the basis of image structures, for example boundary structures or special image characteristics, or on the basis of gray values of the images. In any case only two images are considered and a mapping rule is determined between only two images to be registered, said rule being used to transform one of the two images to the other so that they register. In order to determine the mapping rule, customarily use is made of a similarity measure, but also this measure is determined only for the two images that are examined and have to be registered. One of these two images represents the reference image with which the other image is registered.

In the case of a series of temporally successively acquired images, all images are thus registered with a fixed reference image in the known methods, or each image is registered with the temporally preceding image that has already been registered. The available information, however, is not optimally used in that case, so that the registration accuracy is not optimum. For example, it may occur that a reference image that has been selected for the registration is not optimum for all images to be registered, for example, because structures that are contained in many of the images to be registered are not shown in the reference image. In the case of registration with the respective temporally preceding image, however, registration errors that have occurred during the first registration steps can be taken up in further registration steps and may accumulate or propagate through all registration steps.

The invention, therefore, has for its object to provide a method and a device for the registration of a series of temporally successively acquired images of an object in which said drawbacks have been mitigated and which notably yield an optimum registration result while making optimum use of the information available in the images to be registered.

This object is achieved by means of a method as disclosed in claim 1 and by means of a device as disclosed in claim 8.

The invention is based on the recognition of the fact that for the registration of images, instead of observing each time only two images separately and determining the mapping rule on the basis of a similarity measure calculated for these two images only, it makes more sense to determine a similarity measure from the data of all images so as to determine the mapping rule for two images to be registered, or to determine mapping rules for more than two images, and to use said similarity measure so as to decide whether the quality of the current mapping rule used is adequate or not.

The determination of the mapping rules is preferably performed iteratively as described in claim 2. This means that in a first step one or more mapping rules are selected for one or more images to be registered and that in a second step the similarity measure is

determined for all images to be registered, that is, not only for the image that is being treated at the relevant instant, the images examined during the first step being transformed by way of the selected mapping rules prior to the determination of the similarity measure. On the basis of the similarity measure determined in the second step it is then decided whether the mapping rules selected in the first step are optimum or require further optimization. In the first case one or more further images are examined and the steps 1 and 2 are performed again, whereas in the second case the procedure returns to the step 1 in order to execute a further optimization of the mapping rules for the same images in an iterative manner. A limit value or an extreme value for the similarity measure can thus be used as a criterion for determining whether or not a mapping rule is optimum.

It is advantageous to examine each time only a single image to be registered and to optimize the corresponding mapping rule for this image in conformity with the described method. However, it is also feasible to vary the mapping rules for a plurality of images or all images simultaneously and to determine the similarity measure after each step of the variation process.

Preferably, characteristic structures or characteristic image values in the images are used for the registration, it being possible to select different or identical characteristic features for each image to be registered.

The mapping rules to be determined should preferably compensate for arbitrary geometrical changes of the object imaged, notably for translations, rotations, compressions and expansions. However, it is also feasible to restrict the changes to be compensated, for example to translations.

In a preferred embodiment of the invention the image registration concerns a series of medical images of an object to be examined, notably a series of two-dimensional or three-dimensional images formed by means of a medical imaging modality. All of said images may have been acquired by means of the same medical imaging modality, for example a temporal series of images formed by means of X-ray fluoroscopy. However, the images may also have been acquired by means of different imaging modalities. Thus, it is also possible to register images that have been acquired by means of a magnetic resonance tomography apparatus with images that have been acquired by means of an ultrasound device.

The invention can be used particularly advantageously for functional magnetic resonance tomography wherein temporal series of images of the brain are used for the study of brain activities in response to external stimuli. In order to arrive at reliable results for such a

study, a very high accuracy is required for the registration; such a high accuracy can be achieved by means of the invention.

The invention also relates to a registration device as disclosed in claim 8, which device includes a storage unit for storing images and an arithmetic unit for determining the mapping rules and the similarity measure. The construction of this device may also be further elaborated so as to realize embodiments that are identical or similar to and compatible with the method in accordance with the invention as described above and also as disclosed in the dependent claims for the method.

The invention also relates to a device for the temporally successive acquisition of a series of medical image data from an examination zone of an object to be examined, which device includes a registration device in accordance with the invention. An acquisition device of this kind may be, for example a magnetic resonance tomography apparatus, a computed tomography apparatus, an X-ray device or an ultrasound device.

Finally, the invention also relates to a computer program for carrying out the method in accordance with the invention and/or for controlling the registration device in accordance with the invention.

The invention will be described in detail hereinafter with reference to the drawings. Therein:

Fig. 1 is a block diagram of a first known version of a registration method,

Fig. 2 is a block diagram of a second known version of a registration method,

Fig. 3 is a block diagram of a version of the registration method in accordance with the invention, and

Fig. 4 is a block diagram of an image acquisition device in accordance with the invention.

Fig. 1 shows a block diagram of a first version of a registration method in accordance with the state of the art. This Figure shows, by way of example, four images I_1, I_2, I_3, I_4 of a series of n temporally successively acquired images $I_1 \ldots I_n$ that are to be registered relative to one another. These images may be, for example temporally successively acquired two-dimensional or three-dimensional slice images of the brain of a patient that have been acquired by means of a magnetic resonance tomography apparatus in order to carry out functional studies of individual parts of the brain in response to external stimuli. For the registration it is necessary to derive mapping rules T_2, T_3, $T_4 \ldots T_n$ which are used to transform the original images I_2, I_3, $I_4 \ldots I_n$ into registered images I_1', I_2', I_3', $I_4' \ldots I_n'$ in order to ensure that

these images are registered with one another. The mapping rules T_2, T_3, T_4...T_n thus serve to determine the positional relationships in space between the images I_1 to I_n.

According to the version that is shown each time two neighboring images are registered, which means that first the image I_2 is registered with the image I_1, resulting in the registered image I_2'. Subsequently, the image I_3 is registered with the previously registered image I_2', resulting in the registered image I_3'. Subsequently, the image I_4 is registered with the registered image I_3'; this yields the registered image I_4'.

Two images are registered with one another in such a manner that a first tentative mapping rule T_2 is defined for the image I_2, which rule is used to transform the image I_2 into the image I_2'. The similarity measure M2 is then determined between the image I_2' obtained and the reference image I_1', in this case corresponding to the image I_1, which similarity measure forms an indication as to whether the similarity between the images I_2' and I_1' (or I_1) is adequate so that the mapping rule T_2 need not be further modified. The similarity measure may be determined as, for example the variances of voxels, that is, of individual small image points or groups of image points, in the images I_1' and I_2'. When the similarity measure reveals that the similarity is not yet adequate, the mapping rule is step-wise varied until the similarity measure each time calculated indicates that the similarity between the images I_2' and I_1' is good enough.

The procedure for the registration of an image with the respective preceding, already registered image is identical to the procedure described above. This means that the mapping rule T_3 is determined via the similarity measure M3 between the images I_3' and I_2'. Analogously, the mapping rule T_4 is then determined between the images I_4' and I_3' by way of the similarity measure M4. This procedure continues until all images have been registered with the respective preceding image. This method has the drawback that each image is always registered exclusively with the respective temporally preceding image, so that errors that occur in the first registration steps are propagated in further registration steps.

Fig. 2 shows a second version of a registration method in conformity with the state of the art. In contrast with the version shown in Fig. 1, all images I_2, I_3, I_4...I_n are now registered with a fixed reference image I_1' which again corresponds to the image I_1. The mapping rule T_2 is then determined by means of the similarity measure M2 which is determined from the images I_2' and I_1' as in the version shown in Fig. 1. Unlike in the version shown in Fig. 1, the similarity measure M3 and the similarity measure M4 for determining the mapping rules T_3 and T_4 are determined from the image I_3' and the reference image I_1', and from I_4' and I_1', respectively.

This method, however, has the drawback that it may occur that not all structures that are present in the reference image I_1' and are used for the registration are also present in all other images, so that the registration takes place with different reference points. Conversely, it may also occur that structures that are present in the individual images I_2, I_3, I_4...I_n to be registered and are particularly suitable for the registration are absent in the reference image I_1'.

Fig. 3 shows a block diagram of a version of the method in accordance with the invention. According to this version the mapping rules T_2, T_3, T_4...T_n are all determined on the basis of the same similarity measure M which is determined from all images I_1', I_2', I_3', I_4'...I_n'. The determination of the mapping rules T_2, T_3, T_4...T_n can be performed in steps by determining first the mapping rule T_2, after which the similarity measure M is determined from all images I_1'-I_4' after each variation in order to check whether the mapping rule is good enough. This procedure can be continued until an optimum has been found for the mapping rule T_2. Subsequently, in the next steps the mapping rule T_3 can be determined and subsequently T_4, that is, each time while utilizing the same similarity measure M from all images. Alternatively, some or all mapping rules can be varied simultaneously and subsequently the similarity measure can be determined; this operation is then continued in an alternating fashion until an optimum has been found for the similarity measure M.

Mathematically speaking, the similarity measure can be calculated, for example as a variance of a voxel that is based on a gray value (considered as a function of time), so as to be integrated over the entire image volume; to this end, use is made of the following formula:

$$V(I_1,\ldots,I_n)=\frac{1}{n l_x l_y l_z}\sum_{i=1}^{l_x}\sum_{j=1}^{l_y}\sum_{k=1}^{l_z} W_{ijk}\sum_{t=1}^{n}\left(I_t(i,j,k)-\overline{I_t}(i,j,k)\right)^2.$$

Therein, I_1,...,I_n denote the images of a temporal series and l_x, l_y and l_z denote the number of voxels along each co-ordinate axis. Moreover, it holds that:

$$\overline{I_t}(i,j,k)=\frac{1}{n}\sum_{t=1}^{n} I_t(i,j,k),$$

which indicates the average gray value of a voxel. Moreover, a factor w_{ijk} can be introduced so as to make the effect of voxels that are situated at the edges of the image less than that of voxels that are situated at the at the center of an image.

In order to optimize the similarity measure, n-1 mapping rules must be determined in the case of n images. When fixed transformations with three rotation parameters and three translation parameters are assumed, the total number of parameters thus amounts to 6n-6.

The steps for the iterative determination of the mapping rules will be illustrated hereinafter on the basis of two versions. According to a first version the following steps are executed:

1. Registration of the first two images I_1 (= I_1') and I_2 yields the mapping rule T_2. All other images $I_3,\ldots,I_n$ are ignored during this step. The similarity measure is then given by:

$$V(I_1,I_2)=\frac{1}{2 1_x 1_y 1_z}\sum_{i=1}^{1_x}\sum_{j=1}^{1_y}\sum_{k=1}^{1_z} W_{ijk}\sum_{t=1}^{2}\left(I_t(i,j,k)-\frac{(I_1(i,j,k)+I_2(i,j,k))}{2}\right)^2$$

This yields I_2'.

2. When s images ($I_1',\ldots,I_s'$) have been registered after a plurality of steps, the registration of the image I_{s+1} and the determination of the mapping rule T_{s+1} are obtained by optimization of

$$V(I_1,\ldots,I_{s+1})=\frac{1}{(s+1)1_x 1_y 1_z}\sum_{i=1}^{1_x}\sum_{j=1}^{1_y}\sum_{k=1}^{1_z} W_{ijk}\Big(\sum_{t=1}^{s}(I_t'(i,j,k)-\overline{I_t}'(i,j,k))^2+(I_{s+1}(i,j,k)-\overline{I_{s+1}}'(i,j,k))^2\Big)$$

for which it holds that:

$$\overline{I_t}'(i,j,k)=\frac{1}{s+1}\Big(\sum_{t=1}^{s} I_t(i,j,k)+I_{s+1}(i,j,k)\Big)$$

This results in I'_{s+1}.

3. This iterative procedure is terminated after n-1 iterations, after which $I_1',...,I_n'$ are available.

In conformity with a second version, all images $I_1,...,I_n$ are simultaneously optimized.

The method in accordance with the invention offers a significant improvement of the registration result, that is, of the mapping rules, in comparison with the registration result offered by the known methods.

Fig. 4 shows a device for the temporally successive acquisition of a series of image data, that is, notably medical images of an examination zone of a patient. The device 1 may be, for example a magnetic resonance tomography apparatus and includes a detector 2 for the acquisition of the image data I_1, I_2, ... that is applied to the registration device 3. This device includes on the one hand a storage unit 4 for the storage of the image data and an arithmetic unit 5 for the calculation of the mapping rules and the similarity measure. The registered images I_1', I_2', ... are applied from the device 3 to a further image evaluation unit that is not shown herein.

The invention is restricted neither to the embodiments shown nor to the described application for medical image data. The invention can be used for the registration of arbitrary temporally successively acquired images of the same object for which a high registration accuracy is required in order to compensate notably for motions of the object or of the image acquisition device during the image acquisition. It is feasible, for example, to use the invention also for motion correction of digital video recordings.

The method in accordance with the invention may be carried out by way of a suitable computer program that is executed by an image processing computer. Such a computer program may also be stored in the image data acquisition device and may control a corresponding registration device.